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Comparison between Short Time Fourier and Wavelet Transform for Feature Extraction of Heart Sound

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Abstract

This paper presents the application of the wavelet transform analysis method to the phonocardiogram (PCG) signal. Heart sound is a highly nonstationary signal. So in the analysis of heart sound, it is important to study the frequency and time information. To investigate the exact features of heart sound, we adopt Short-Time Fourier Transform (STFT) and Wavelet Transform (WT) as time-frequency representation. As a result, it is found that the STFT analysis cannot detect the four components of the first sound in the PCG signal and the two components of the second sound are inaccurately detected. On the other hand, It is found that the wavelet transform is capable of detecting the two components, the aortic valve component A2 and pulmonary valve component P2, of the second sound S2 in a normal PCG signal. Furthermore, wavelet transform provides more features and characteristics of the PCG signals that will help physician to obtain qualitative and quantitative measurements of the heart sound.

Ⅰ. INTRODUCTION

Heart sound provides clinicians with valuable diagnostic and prognostic information. Phonocardiography by auscultation is non-invasive and provides valuable information concerning the heart valves and hemodynamics. But the phonocardiogram(PCG) is a complex signal that is very difficult to analyze visually.

After the audible pulsation of the heart was first described in 1628 by William Harvey, many physicians with the invention of the stethoscope have studied and written about the sounds of the heart[6]. The first phonocardiography developed by Einthoven in 1894 was based on Lippman's capillary electrometer previously used to record the first electrocardiogram. The basic aims of phonocardiography were to provide the physician with a complementary tool to record the heart sounds and murmurs during auscultation, to obtain specific measurements on their timing, and to get a better understanding of the basic mechanisms behind genesis. Although the development of the intracardiac phonocardiography at the beginning of the 1959's and Doppler echocardiography have provided new approach to investigate the basic mechanisms involved in the genesis of the heart sounds and murmurs, heart auscultation is a easy and useful first aid clinical tool. But, heart sound analysis by auscultation is a qualitative and insufficient method to diagnose some heart diseases. Abnormal heart sounds may contain, in addition to the first sound S1 and second sound S2, murmurs and aberrations caused by different pathologies of the cardiovascular system. These aberrations confused the human ear, obscuring the main sound of the heart. So the analyst can not obtain both qualitative and quantitative characteristics of a phonocardiogram[6]. Recently new developments have been ocurred owing to developments of DSP technology. Main characteristics, such as timing of heart sound and their components, frequency content, location, location in cardiac cycle and envelope shape of murmurs, can be quantified using digital signal processing technique[2]. Heart sound is a highly non-stationary signal. So in the analysis of heart sound, it is important to study the frequency and time information. Moreover, heart sounds exhibit sudden frequency changes and transients. To measure and quantify important features such as the time instants of heart sounds and their frequency changes with time, a sophisticated quantitative method is needed.

To investigate the exact features of the heart sound, we adopt Short-Time Fourier Transform(STFT) and Wavelet Transform(WT) as a time-frequency representation. The STFT cannot track very sensitive sudden changes in time direction. On the other hand, the wavelet transform has analyzed the heart sound more accurately than STFT technique. And to obtain a more detailed and flexible result we adopt the wavelet packet method.

Ⅱ. MODELING OF HEART SOUND

The most widely accepted theory on the genesis of the heart sound is described by Rushmer and states that heart sound consists of four components[2]. The first heart sound (S1) occurs at the beginning of ventricular contraction during the closure of the mitral and tricuspid valves. It indicates the beginning of ventricular systole. The second heart sound(S2) marks the end of ventricular systole and the beginning of ventricular relaxation, following the closure of the aortic and the pulmonary valves. The identification of systole and diastole is important in determining other heart sound and murmurs[1],[5]. The third sound(S3) is caused by the

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oscillations of the blood between the root of the aorta and the ventricular wall. The last sound(S4) is caused by the turbulence of the ejected blood. The third and fourth heart sound (S3 and S4) caused by the sudden termination of the ventricular rapid-filling phase, after isovolumetric relaxation, and the displacement of blood caused by arterial contraction, respectively[6]. The first and second heart sounds are regarded as the normal heart sounds. The third and fourth heart sounds are normal in young persons, but pathological in older adults. In addition to these four heart sounds, other transient sounds such as opening clicks, snaps, and prolapsed sound can be caused sometimes during systole and diastole. These sounds are produced by valvular stenosis or by some other abnormalities of the mitral and tricuspid valves. Heart murmurs also may be present in the PCG, are generally associated with abnormal function of the cardiac valve, except for the innocent murmurs which may occur during systole in young persons with normal hearts. The murmur can be classified as systolic murmurs and diastolic murmurs according to their production phase. Although heart sound recordings or phonocardiogram have repetitive nature, they cannot be easily classified as a simple periodic signal.

The PCG is non-stationary and composed of multiple components caused by complex mechanoacoustic events.

Ⅲ. THE FOURIER TRANSFORM AND STFT

The FT X(w) of a signal x(t) is defined as:

$$X(\omega) = \int x(t) e^{-j\omega t} dt \qquad (1)$$

where t and w are the time and frequency parameters, respectively. It defines the spectrum of x(t) which consists of components at all frequencies over the range for which it is nonzero. For many signals, Fourier analysis is extremely useful because the signal's frequency content is of great importance. But Fourier analysis has a serious drawback. In transforming to the frequency domain, time information is lost. If a signal doesn't change much over time, it is called a stationary signal, this drawback isn't very important. However, most signals like PCG signal contains numerous non-stationary characteristics – drift, trends, abrupt changes, and beginning and end of events. These characteristics are often the most important part of the signal and Fourier analysis is not suited to detecting them.

In an effort to correct this deficiency, Dennis Gabor (1946) adapted the Fourier transform to analyze only a small section of the signal at a time. It is called the Short-Time Fourier Transform(STFT)[1],[5].

The STFT is obtained from the usual FT by multiplying the time signal x(t) by an appropriate sliding time window w(t). The location of the sliding window adds a time dimension and gets a time-varying frequency analysis. Thus, instead of the usual FT expression one gets a time-frequency expansion of the form:

$$X(t,\omega) = \int x(t) w(\tau - t) e^{-j\omega\tau} d\tau \qquad (2)$$

where w(t)is the time window applied to the signal.

It provides some information about time and frequencies that a signal event occurs. However, one can only obtain this information with limited precision, which is determined by the size of the window. Also it has strict limitations on time-frequency resolution. If greater frequency resolution is required, it can be achieved only at the expense of temporal resolution. Many signals require a more flexible approach-one where we can vary the window size to determine more accurately either time or frequency.

Ⅳ. THE WAVELET TRANSFORM

A. Definition

The Wavelet Transform(WT) is also used to analyze the heart sound in time and frequency domains. The wavelet transform of a signal x(t) with respect to an analysis

$$WT(t,a) = \frac{1}{\sqrt{a}} \int x(\tau) g^*(\frac{t-\tau}{a}) d\tau$$
$$= \sqrt{a} \int X(\omega) G^*(a\omega) e^{j\omega t} d\omega \qquad (3)$$

wavelet g(t) is defined as:

where * denotes a complex conjugate, g(t) is the so-called analyzing wavelet. X(w) and G(w) are the Fourier transforms of x(t) and g(t), respectively. The parameter 'a' is a scaling parameter which is inversely proportional to frequency[3].

The analyzing wavelet g(t) should satisfy a certain number of properties. The importance is integrability, square integrability. And the wavelet has to be concentrated in the time and frequency as much as possible.

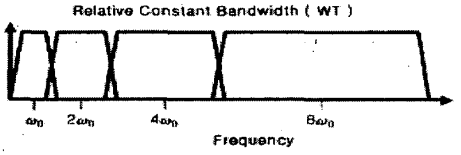


Figure 1. Frequency decomposition of DWT.

B. Wavelet packet Analysis

The wavelet packet method is a generalization of wavelet decomposition that offers a richer range of possibilities for signal analysis. Compared with the wavelet framework, the wavelet packets offer a more complex and flexible analysis. In wavelet packet analysis, the detail as well as approximations can be split. This yields 2^ndifferent ways to encode the signal.

Choosing one out of all these possible encodings presents an interesting problem. In this paper, we use an entropy-based criterion to select the most suitable decomposition of a given signal. This means we look at each node of the decomposition tree and quantify the information to be gained by performing each split. The packet analysis can be done by finding the "best tree" based on an entropy criterion. We used the Shannon entropy. :

$$E(s) = -\sum_i s_i^2 \log(s_i^2) \qquad (4)$$

Expressions 's' is the signal and 's_i' the coefficients of s in an orthonormal basis.

We use the following basic step in order to find the optimal subtree with respect to a given entropy criterion E.

The Shannon entropy accentuates the effect of low value noise that makes the envelope too noisy to read. The absolute value gives the same weight to all the signal. The Shannon energy emphasizes the medium intensity signal and attenuates the effect of low intensity signal much more than that of high intensity signal.

V. EXPERIMENTAL RESULTS AND DISCUSSION

A. The Short-Time Fourier Transform

Figure 2 shows one second of a normal heart sound signal which contain the two major sounds S1 and S2. The sampling rate used is 8000 samples/s.

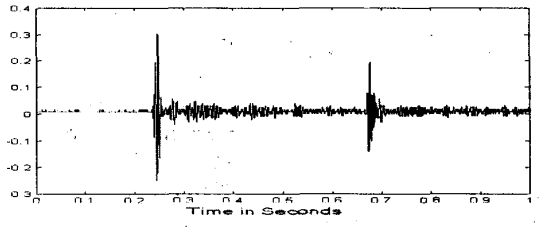
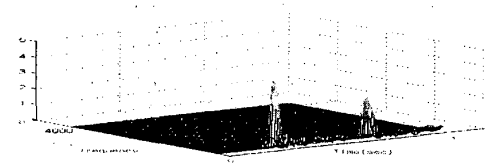
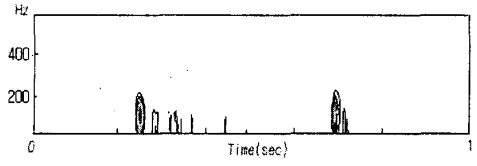


Figure 2. Original signal (PCG).

Figure 3(a), (b) shows the STFT of the normal heart sound signal of original signal(figure 2). The time window length used is 32 points, and the FFT length that STFT used is 128 points. It is shown that the four components of the first sound S1 are not detected, and the two components A2 and P2 of the second sound are not accurately represented. Only the frequency and the time of S1, S2 are detected. In order to analyze this signal more accurately using the STFT, one may think of increasing the sampling rate of the original signal. While the STFT analysis between time and frequency information can be useful, we cannot analyze accurately signals with sharp changes like the heart sound, because once you choose a particular size for the time window, that window is the same all frequency.



(a)

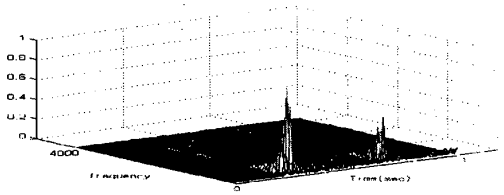


(b)

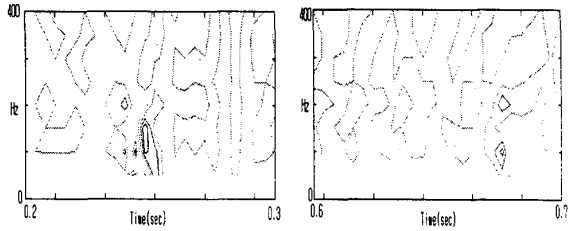
Figure 3. (a) STFT of original heart sound signal. **(b)** Contour plot of the surface in (a).

B. The Wavelet Transform

Figure 4(a) shows the WT of the original PCG signal, figure 4(b) and 4(c) shows the contour plot of the WT of S1, S2 respectively. The spectrum of S1 has reasonable values in the range 10-200Hz. S1 is clearly resolved into four components. The spectrum of S1 shows that most of the energy of S1 seems to be concentrated in its second and third components. S2 is clearly resolved into two components-the aortic valve component A2 and the pulmonary valve component P2. A2 and P2 are due to closure of the aortic and pulmonary valves, respectively. The frequency of A2, P2 is detected. A2 and P2 are important information in heart sound. The wavelet transform allows us to measure and determine this frequency difference and thus allows a diagnostic process regarding this parameter.



(a)



(b) (c)

Figure 4. (a) WT of original heart sound signal. **(b)** Contour plot of S1 in (a). **(c)** Contour plot of S2 in (a)

C. The Wavelet Packet method

The wavelet packet can be used for numerous expansion of a given signal. We use an entropy-based criterion to select the most suitable decomposition of a given signal.

Figure 5(a) shows the best tree of the original signal to level 6 using the Shannon entropy. For PCG signals, the low-frequency content is the most important part. So we decomposed the low frequency part continuously.

Figure 5(b) shows the analysis of the original PCG signal using the wavelet packet method. We can obtain more good result than that used the wavelet transform.

The wavelet packet method is more flexible method than the wavelet transform. The time delay between A2 and P2 can be estimated as 10ms, the aortic valve normally closes before the pulmonary valve and hence A2 should precede

P2. The length of this delay is important in diagnosis since its length is directly related to different pathologies.

Four components of S1 are more accurately and flexibly detected than that of the wavelet transform. And, P2 is more weakly detected than A2.

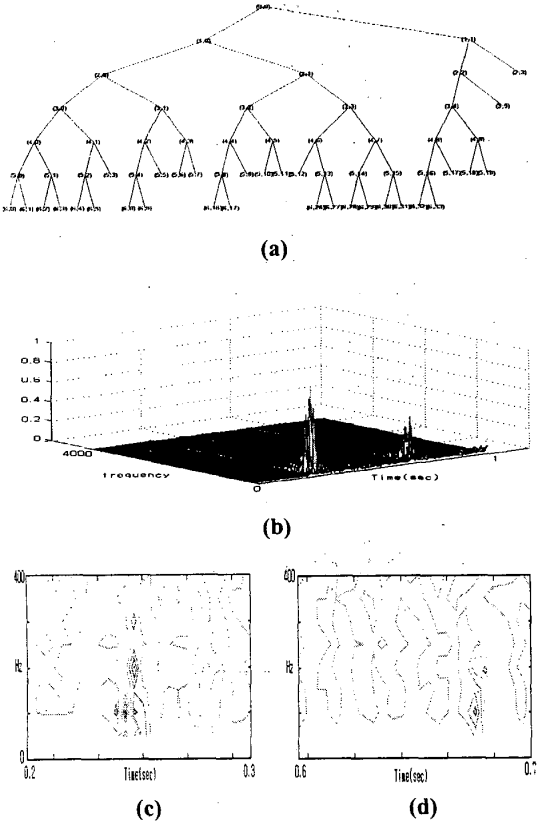


Figure 5. (a) The best tree of the wavelet packet. **(b)** A transform using the wavelet packet method of original heart sound signal. **(c)** Contour plot of S1 in (b). **(d)** Contour plot of S2 in (b)

VI. CONCLUSIONS

Phonocardiogram signal is very a complex signal. PCG signal contains numerous nonstationary or transitory characteristics - timing of heart sound, their components, location in cardiac cycle. Specially, the PCG signals are characterized by transient and fast change in frequency as time progress. To find these characteristics, the time-frequency analysis technique can provide better diagnostic information than the normal fourier transform.

We have presented the applications of the short-time fourier transform, wavelet transform and wavelet packet method to PCG signal analysis. A comparison of the three methods has been shown the resolution differences among them.

It is found that the STFT cannot detect several features, such as the four components of the first sound and two components of the second sound. On the other hand, it is found that the WT is capable of detecting the two components, the aortic valve component A2 and the pulmonary valve component P2, of the second sound in normal PCG signal. Therefore, the wavelet transform produces a diagnostic process regarding abnormalities in the aortic and pulmonary valves. A time-frequency analysis obtained by the WT gives more detail about the characteristics of the PCG signals at low frequency range. Because the features that represent more precisely the characteristics of heart sound are in specific low frequency band, we applied the wavelet packet analysis to PCG signals. We can obtain more flexible results. If we search the most appropriate packet, we will obtain ideal results.

Finally, we conclude that the wavelet analysis is more successful than the short-time Fourier analysis at the same condition to extract the features of phonocardiogram for recognition. This will help in improving the diagnostic techniques of the heart diseases in cost-effective approaches.

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